An Update on Modes and Timing of Gamete and Planula Release in Hawaiian Scleractinian Corals with Implications for Conservation and Management[1]

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Abstract: Reproductive data for 24 of the 50 plus species of scleractinian corals in Hawai'i are available. A majority of species (75%) are broadcast spawners, just over half (58%) of which are hermaphrodites. Peak reproduction of Hawaiian corals occurs during summer months, although reproduction continues year-round for some brooders. Timing, duration, mode, and location of reproductive processes have implications for disturbance management, assessment, and conservation of reef corals.

THE MINIMIZATION OF human impacts on coral reef dynamics is critical to maintaining coral reef diversity and reef ecosystem functions. Human impacts can be direct and/or indirect, affecting reef organisms during one or more of a variety of life history stages (Brown and Howard 1985, Richmond 1993, 1997, Raimondi and Reed 1996). Sexual reproduction in scleractinian corals involves a number of discrete stages that occur in different zones of the marine environment. These fundamental stages include gamete development (internal to the organism), gamete release (internal coordination leading to external release), fertilization (internal, or external in the water column, at the water surface, or on the benthos), embryonic and larval development (internal, or external in the water column or at the water surface), dispersal (external in the water column and/or at the water surface), settlement, and metamorphosis (external on a substrate) (Harrison and Wallace 1990, Richmond 1993, 1997). Synchronization of various reproductive stages within populations is fundamental to increasing the likelihood of reproductive success (Harrison and Wallace 1990, Levitan 1995, Morgan 1995, Coma et al. 1998). Individual stages may differ in their exposure, vulnerability, and susceptibility to various impacts (Richmond 1993, 1997).

Understanding where and when reproductive processes take place allows for a precautionary approach to minimizing human interference with coral reproductive dynamics. In this paper we summarize available data for reproduction in Hawaiian corals in an effort to provide information pertinent to mitigating human impacts on coral reproduction and population dynamics.

MATERIALS AND METHODS

Data summarized in this report resulted from both direct and indirect observations of gamete formation and release in laboratory and/or field settings. Information for the majority of species came from studies conducted at the Hawai'i Institute of Marine Biology and a review of the literature (including reviews by Fadlallah 1983, Richmond and Hunter 1990, and Richmond 1997). Although Hawaiian coral taxonomy is currently in a state of flux, Maragos (1995) was used as a guide (see Maragos 1977 for reported synonyms).

RESULTS

Information on modes and timing of gamete and planula release for 24 of roughly 50 Hawaiian scleractinian coral species (Maragos 1995) is provided in Table 1. The data cover the majority of the most common inshore

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TABLE 1

Reproductive Characteristics of Hawaiian Scleractinian Coral Species Listed by Maragos (1995)

Species	Sex[a]	Mode[b]	Season[c]	Moon Phase	Spawning Times	Location of Fertilization	Reference
ACROPORIDAE							
Acropora cytherea (Dana, 1846)	H	*S	*Lt. Sp–Sr		*June–Aug.		Kenyon (1992, 1994)
A. humilis (Dana, 1846)	H	*S	Lt. Sp	*1st qtr	*June	*Surface	Kenyon (1992, 1994)
A. paniculata Verrill, 1902							
A. valida (Dana, 1846)	H	*S	Sr	*New–4th qtr?	*July–Aug.	*Surface	Kenyon (1992, 1994)
Montipora capitata (Dana, 1846)	H	S	Lt. Sp–Sr	New–1st qtr	May–Sept., 20:45–22:30	Surface	Heyward (1986), Hodgson (1988), Hunter (1988*b*), Cox (1991)
M. dilatata Studer, 1901	H	S	Sr	New, Full–3rd qtr	July–Aug., 20:30–21:45	Surface	Heyward (1986), Hodgson (1988), Hunter (1988*b*)
M. flabellata Studer, 1901	H	S	Sr–*F		July–*Sept., 21:05–21:50	Surface	Heyward (1986), this study
M. patula Verrill, 1864	H	S	Sr	New–1st qtr, Full–3rd qtr	July–Sept., 22:05–23:10	Surface	Hodgson (1988), this study
M. studeri Vaughan, 1907	H	S	Sr	New–1st qtr, Full–3rd qtr	July–Sept., 22:23–23:00	Surface	Heyward (1986), Mate (1998)
M. tuberculosa (Lamarck, 1816)							
M. verrilli Vaughan, 1907	H	*S	Sr	Full–3rd qtr	July	*Surface	Heyward (1986)
AGARICIIDAE							
Gardineroseris planulata (Dana, 1846)							
Leptoseris hawaiiensis Vaughan, 1907							
L. incrustans (Quelch, 1886)							
L. mycetoseroides Wells, 1954							
L. papyracea (Dana, 1846)							
L. scabra Vaughan, 1907							
L. tubulifera Vaughan, 1907							
Pavona duerdeni Vaughan, 1907	G	S				*Water column	G. Hodgson, unpubl. data
P. varians Verrill, 1864	G	S	Lt. Sp	Full–3rd qtr	June, 19:05–20:15	*Water column/ surface	G. Hodgson, unpubl. data; Mate (1998); this study
P. maldivensis (Gardiner, 1905)							

BALANOPHYLLIDAE							
Balanophyllia sp. cf. *affinis* (Semper, 1872)							
B. hawaiiensis Vaughan, 1907							
DENDROPHYLLIDAE							
Tubastrea coccinea Lesson, 1831		B	Lt. Sp–W	All	June–Jan., diurnal and nocturnal	Polyps	Edmondson (1929, 1946), Jokiel et al. (1985); A. M. Tarrant and S.P.K., unpubl. data
FAVIIDAE							
Cyphastrea ocellina (Dana, 1846)	H	B	Yr	All		Polyps	Edmondson (1929, 1946), Stimson (1978), Jokiel et al. (1985), Wright (1986)
Leptastrea bottae (Milne-Edwards & Haime, 1850)	G	S				*Water column	G. Hodgson, unpubl. data
L. purpurea Dana, 1846	G	S				*Water column	G. Hodgson, unpubl. data
FUNGIIDAE							
Cycloseris tenuis (Dana, 1846)							
C. vaughani (Boschma, 1923)							
Diaseris distorta (Michelin, 1843)							
Fungia scutaria Lamarck, 1801	G	S	Sr–F	Full–3rd qtr	June–Nov., 17:00–19:00	Water column	Krupp (1983), Schwarz et al. (1999)
POCILLOPORIDAE							
Pocillopora damicornis (Linnaeus, 1758)	H	B	Yr	All	Diurnal and nocturnal	Polyps	Edmondson (1946), Reed (1971), Harrigan (1972), Stimson (1978), Richmond and Jokiel (1984), Jokiel (1985)
P. eydouxi Milne-Edwards & Haime, 1860							
P. ligulata Dana, 1846							
P. meandrina Dana, 1846	H	S	Sp	Full–3rd qtr	Apr.–May, 07:20–08:15	Water column	Stimson (1978), Fiene-Severns (1998); S.P.K., A. M. Tarrant, and E.F.C., unpubl. data
P. molokensis Vaughan, 1907							

TABLE 1 (continued)

Species	Sex[a]	Mode[b]	Season[c]	Moon Phase	Spawning Times	Location of Fertilization	Reference
PORITIDAE							
Porites brighami Vaughan, 1907	G, H	B	Sr			Polyps	Hunter and Hodgson in Richmond and Hunter (1990)
P. compressa Dana, 1848	G	S	Sr	Full–3rd qtr	June–Sept., 23:00–01:30	Water column	Hunter (1988*a*), this study
P. duerdeni Vaughan, 1907							
P. evermanni Vaughan, 1907	G	S	Sr	Full, 4th qtr	Aug.–Sept.	*Water column	Hunter and Hodgson in Richmond and Hunter (1990), Neves (1998)
P. lichen Dana, 1846	H	B				Polyps	G. Hodgson, unpubl. data
P. lobata Dana, 1846	G	S	Lt. Sp–Sr	Full–3rd qtr	June–Aug., 01:20–03:14	Water column	Hunter and Hodgson in Richmond and Hunter (1990), Mate (1998), Neves (1998), this study
P. pukoensis Vaughan, 1907							
P. rus (Forsskål, 1775)							
RHIZANGIIDAE							
Culicia sp. cf. *tenella* Dana, 1846							
SIDERASTREIDAE							
Coscinaraea wellsi Veron & Pichon, 1979							
Psammocora explanulata Van der Horst, 1921							
P. nierstraszi Van der Horst, 1922							
P. stellata Verrill, 1864		*B (?)	Sr	Full	July, *19:50–21:00	*Polyps	This study
P. verrilli Vaughan, 1907							

Note: *, inferred; Lt., late.
[a] G, gonochoric; H, hermaphroditic.
[b] B, brooder; S, spawner.
[c] Sp, spring; Sr, summer; F, fall; W, winter; Yr, year-round.

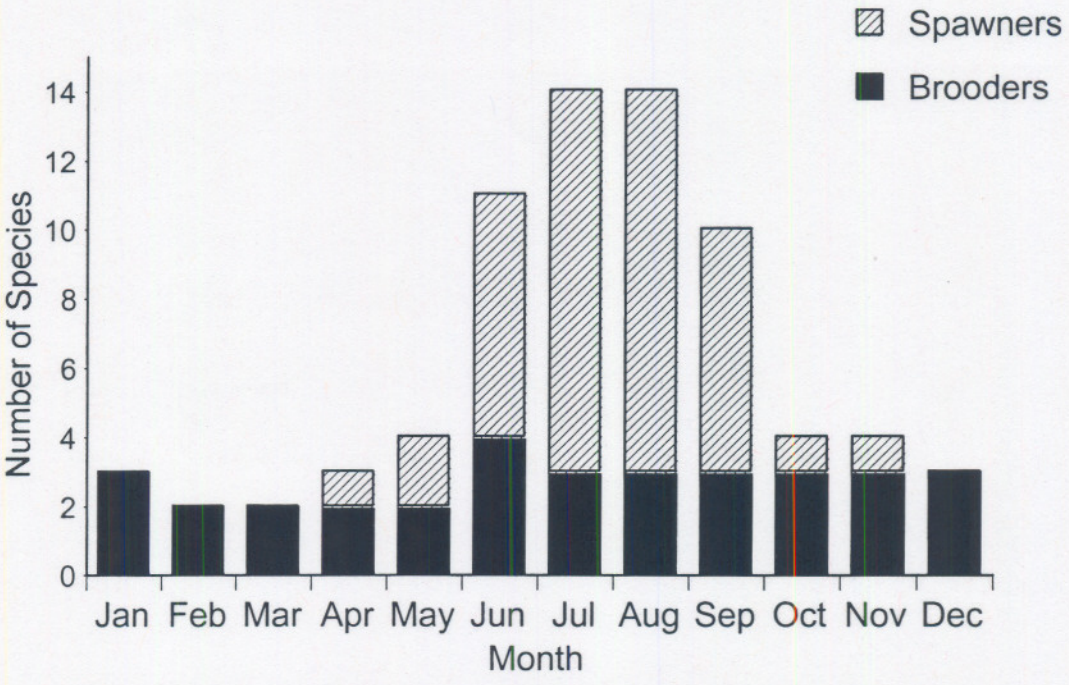

FIGURE 1. Known number of scleractinian coral species planulating and spawning each month in Hawaiian waters.

shallow-water species but are far from complete. Six (25%) of the 24 species brood larvae, 10 (42%) are broadcast-spawning hermaphrodites, and eight (33%) are gonochoric broadcast spawners. Seventeen species (71%) display peak reproductive development and gamete or planula release during summer, at least five species (21%) extend release into fall, three species (13%) continue release into winter, and nine species (38%) begin or continue reproductive release in the spring (Figure 1). Fertilization in the Hawaiian Acroporidae is overwhelmingly a surface phenomenon. In brooding species syngamy is presumed to take place within polyps. Zygote formation in gonochoric broadcast spawners is likely to occur within the water column, but surface fertilization may also take place. Although specific timing of gamete release appears discrete and predictable, spawning for most species occurs over a number of days and months, indicating variability and possible plasticity in seasonal synchrony of spawning events.

The classification of *Psammacora stellata* as a brooder in this study is tentative and in need of verification. It is based on the tank collection of swimming coral larvae 45 min after previous examination of secluded colonies. We made direct observations on mode and timing of reproductive release of *Montipora patula* colonies over multiple reproductive seasons, as well as observations confirming the reproductive activities of *M. capitata*, *Pavona varians*, *Tubastrea coccinea*, *Cyphastrea ocellina*, *Fungia scutaria*, *Pocillopora damicornis*, *P. meandrina*, *Porites compressa*, and *P. lobata*. Observations of *Montipora flabellata* spawning were limited, and species identification of the morphological variant used in this study is in need of verification and congruence of multiple coral taxonomists.

DISCUSSION

Any assessment of potential impacts to Hawaiian reef corals must take into consideration local population structure and timing